PEM Stack Testing and Evaluation

Kenneth Stroh , Nicholas Vanderborgh, José Tafoya, Michael Inbody, James Hedstrom,
Kirk Weisbrod Lois Zook, Jerry Taylor, Michael Banaszek, James Smith and James Lee
MS J576, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545
(505) 667-6651, fax: (505) 665-6173

Objectives

- Perform evaluation at the PEM stack level to document effects of anode feed composition on stack performance.
- Evaluate mathematically and experimentally novel stack operating scenarios that have promise in increasing performance.
- Investigate stack level thermal management, including operating and design options.
- Investigate technical problems of interest to DOE/OAAT industrial developers.

Approach

- Maintain, utilize and expand a highly capable, flexible engineering-scale stack testing environment.
- Maintain flexible, reliable and unique test hardware.
- Use test results, models and separate-effects tests (such as flow visualization) to evaluate operating strategies, design options, and to project PEM fuel cell system-level effects.
- Maintain a set of competent mathematical tools to predict and analyze test results.
- Respond to requests for focused experiments that support DOE/OAAT industrial partners.

Accomplishments

- Participated in the first engineering-scale experiment to demonstrate technical feasibility of using a hydrogen-rich gas stream derived from gasoline to make electricity in a PEM fuel cell stack, at the Laboratories of Arthur D. Little (ADL) in Cambridge, Massachusetts, including stack operations during fuel processor transients.
- Using a controlled temperature test environment, demonstrated cold soaking, cold-start, and full recovery of a large PEM stack repeatedly over the range from -4˚C to -18˚C with no apparent degradation in performance.
- Improved stack test stand transient capability and measurement techniques, to extend testing to both externally imposed transients and innovative transient operating modes.
- Took delivery and began testing of two 68-cell 3-kW (nominal) Analytic Power PEM stacks and one 10-cell "short stack," designed for easy reconfiguration and using lightly loaded contemporary state-of-the-art membrane electrode assemblies.

Future Directions

- Address issues of PEM stack operation, reactant composition and purity, stack thermal management including environmental extremes, and stack diagnostics and control, to optimize performance, through careful testing (both static and dynamic) and focused modeling. Evaluate future designs selected for low cost manufacturing.

Integrated Fuel Processor-PROX-PEM Stack Experiment

As part of the first engineering-scale demonstration of the technical feasibility of using a hydrogen-rich gas stream processed from gasoline to make electricity in a PEM fuel cell stack, Los Alamos provided a Ballard Mark 5 stack (serial number 212) and necessary support equipment, along with the preferential oxidation (PROX) reactor system for carbon monoxide (CO) cleanup described earlier in this report. In addition to the 5-kW stack, the test stand shipped to the ADL laboratories in Cambridge, Massachusetts, incorporated an electronically-controlled electrical load, reactant flow and pressure management, a deionized-water loop for stack cooling and internal humidification, a building-water loop for heat rejection, flammable and toxic gas leak detection, and an automatic safety system initiating isolation, rapid controlled venting, nitrogen purge, electrical load shedding, and powering down the test-stand, all under computer control. All relevant data, including individual cell voltages, were logged to a data acquisition system.

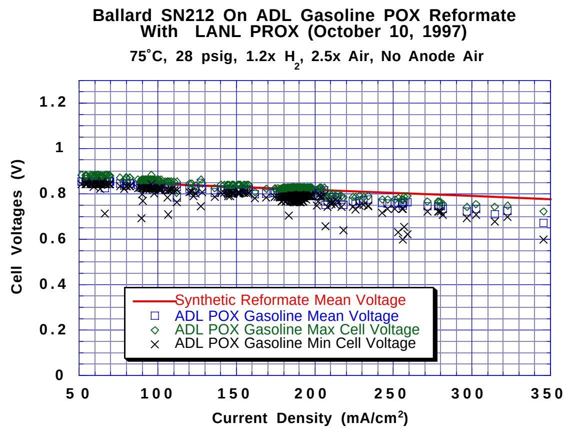

Fig. 2 Polarization curve for a Ballard Mark 5 stack operating on actual partial oxidation gasoline reformate subject to treatment within the Los Alamos PROX. Solid line is performance on "ideal" synthetic ($40\%H_2$, $40\%N_2$, $20\%CO_2$).

These experiments were short in duration and thus stack measurement time was limited. The Ballard stack hardware was included to document PROX performance, while the newly developed Plug Power L.L.C. stack had priority in the experimental plan. The ADL fuel processor exhibited unstable behavior at times. Consequently data collection was not continuous. Nonetheless, a stack polarization curve up to a current density of about 350 mA/cm^2 was generated, and power levels approaching 2 kW gross electric were demonstrated, as shown in Figs. 1 and 2. Though this limited range of current density values, the stack operated with stable performance.

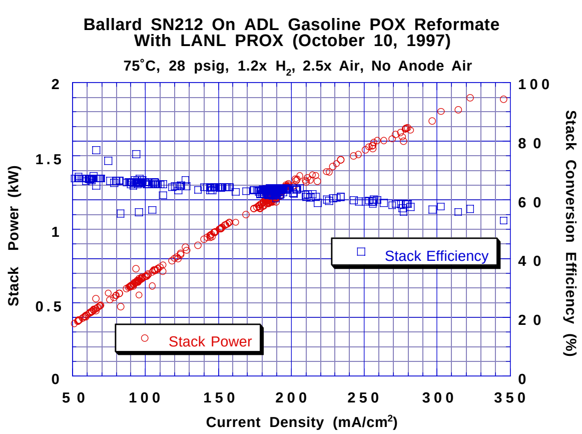

Fig. 1 Power and conversion efficiency for Ballard Mark 5 stack operating on real partial oxidation gasoline reformate using the Los Alamos PROX.

Additional data were collected during "off normal" fuel processor transients. The nature and cause of these transients were not defined, but stack data collected (anode pressure drop and PROX outlet carbon monoxide concentration) indicate both a significant reduction in fuel-processor flow and a considerable change in the chemical composition of the process feed during these events. Almost always, because one or more of the individual cells in the Ballard hardware approached a lower voltage limit, the stack load was automatically switched off and the anode flow bypassed during the majority of the transient. This automatic control was done to assure the stack only experienced acceptable operating conditions. However not all upsets were so severe that the

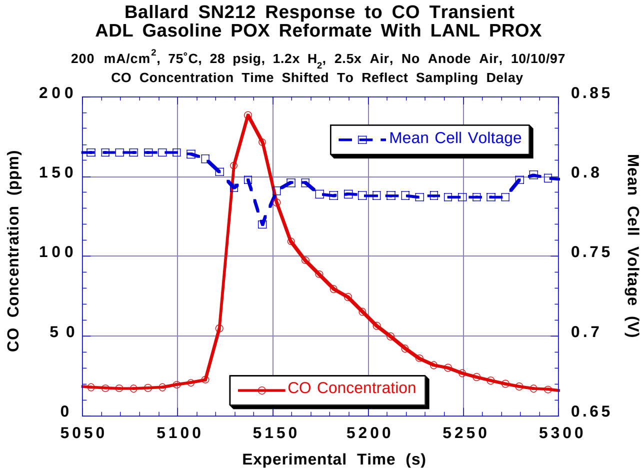

Fig. 3 Response of the Ballard Mark 5 stack to a partial oxidation gasoline reformer transient using the Los Alamos PROX operating with steady control parameters.

automatic control system terminated stack operation. Fig. 3 shows the response of the Ballard stack to one such event where the stack was left on line. Detailed data analysis suggests the performance drop was not entirely due to CO poisoning, although CO was a problem. Individual cell voltage levels were far from uniform. Individual cell voltages in those anodes adjacent to a cooling plate (Ballard Mark 5 stacks feature one cooling plate per every two active cells) were apparently low in performance. Such a performance loss is most likely caused by a sharp reduction in anode flow leading to liquid-water-caused channel blockage. Thus, even though these limited data do not lead to definitive conclusions, the complexity of engineering-scale stack response to changes in operating conditions was clearly demonstrated. The importance of understanding the tolerance of the stack to transient CO levels, which could be considerably higher than similar tolerance to steady-state CO levels, was also apparent. In sum, both the fluid dynamics and the gas composition resulted in significant performance changes.

Low Temperature PEM Stack Testing

We also completed the initial round of stack freezing tests begun last year requested by DOE/OAAT to support Ford Motor Company. A Ballard Mark 5 stack was installed in a computer-controlled environmental chamber and as part of the LANL stack test hardware. The stack was exposed to low temperature test conditions during three different experiments: once to -4˚C and twice to -18˚C (about 0˚F). Prior to low temperature conditions, the stack cooling loop was drained, and the cooling loop, anode and cathode (including humidifiers) were "de-watered" using dry nitrogen. (This purge was completed at ambient temperature.) Because the stack sealing features were not necessarily designed for these cold temperatures, the stack bladder pressure was maintained with the continuous application of 100 psi fill gas to ensure the stack and seals remained compressed.

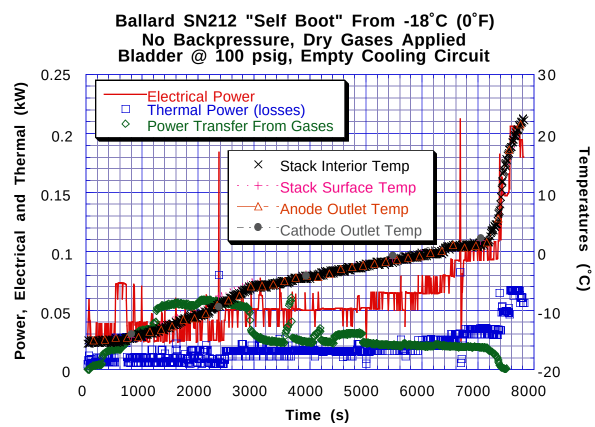

Fig. 4 Thermal response of the Ballard Mark 5 stack to application of reactant gases and a small electrical load at -18˚C.

The first experiment cautiously cooled the stack, lowering the chamber temperature on a - 6˚C per hour ramp from ambient to just below the freezing point of water and held that temperature until the stack was in thermal equilibrium with the chamber (as indicated by temperature measurements derived using several external and internal thermocouples). The stack was then allowed to slowly return to ambient temperature. The flow of deionized water coolant was reintroduced, and the stack was then heated by adding thermal energy to the cooling loop until normal operating temperature (70˚C) was achieved. The -18˚C tests included an overnight cold soak at that temperature. The third test was also done following a overnight cold soak, but then included a "cold start" from -18˚C, initiated by applying ambient pressure, cold hydrogen and air to the anode and cathode. Following verification of individual-cell open-circuit voltages, a small load was applied. Figure 4 shows the 2-hour startup/thaw transient, showing thermal power deposited in the stack from inefficiencies and from the heat capacity of the reactant gases, together with the stack thermal response. As can be seen, stack performance levels during the beginning of the cold-start experiment were rather low, so low that the heating rate was controlled far more by the enthalpy of the reactant feeds than by the waste heated generated during the electrochemical reaction.

The low performance of one single cell hampered startup in the first and last tests (a different cell each time), though in both cases that deviant cell fully recovered voltage performance following imposing a high flow, high differential pressure anode flow transient (7-10 psid required) after thawing. This results suggests the dewatering procedure should have applied this same magnitude of pressure differential to adequately remove liquid water prior to freezing. However, even so the anode flow features may have remained water filled. Comparison of polarization curves before and after the tests show no significant degradation due to these freeze-thaw cycles and transients. Although not mentioned above, each measurement regime was preceded with cross-over measurements, a standard test procedure at Los Alamos to assure no significant anode-to-cathode leakage rate. Although details are design-specific, these tests demonstrated that at least these Ballard PEM fuel cell stacks can be rugged enough to survive freezing with no subsequent loss in performance when the stack is again heated to usual operating conditions

Advanced PEM Fuel Cell Hardware; Development of New Diagnostic Tools.

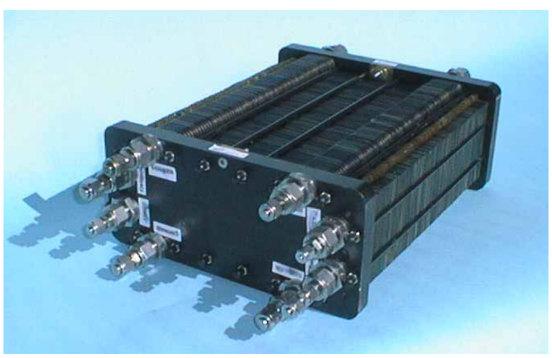

Fig. 5 Analytic Power FC3000 68-cell,
3-kW stack, designed for easy reconfiguration by Los Alamos.

We recently acquired a new and powerful capability for advanced stack testing, with delivery of "take-apart" stack hardware from Analytic Power Corporation (see Fig. 5). The fuel cells feature "modern" membrane electrode assemblies (W.L. Gore PRIMEA® 5500 Series, 0.3 mg/cm^2 Pt cathode, 0.3 mg/cm^2 Pt/Ru anode), leading to reformate testing on prototypical stack devices. In addition, this hardware will allow us to reconfigure full stacks and few-cell short stacks as needed to support advanced operation and diagnostics. Modifications are expected to include alternate flow fields, diffusion layers, and novel MEAs, as well as entirely new hardware such as alternate cooling plates and "diagnostic" plates incorporating extensive instrumentation and sampling ports. The ability to disassemble the stack and maintain it will facilitate tests that are intentionally damaging to MEAs, such as impurity testing, severe transients or other environmental tests, and experiments in accelerated aging.. Engineering drawings of stack internals will allow fabrication of alternate or special parts as needed.

PEM stack testing at Los Alamos relies on maintaining and improving a flexible and safe test environment. During this fiscal year, test stand controls were improved to support advanced testing, such as periodic flow-direction reversal within the cathode and anode flow fields, and to provide more-realistic synthetic reformate operation (steam addition to match expected reformate water concentration). The operator interface was improved, as were the formal test protocols.